NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 1042

THE EFFECT OF SET SIZE ON COLOR RECOGNITION

by

Alan R. Jacobsen and David F. Neri

Naval Medical Research and Development Command
Research Work Unit M0100.001-1022

Released by:

W. C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory
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SUMMARY PAGE

PROBLEM

To determine what effect the set size of a group of colors has on the time required to recognize whether or not a target color belongs to the set.

FINDINGS

Increasing set size from one to two colors results in a significant increase in time to recognize individual colors; however, further increases in set size, up to seven colors, causes little, if any, additional increase in time to recognition.

APPLICATION

It appears that the use of up to seven colors on sonar displays, where memory for color would be important, will have little or no detrimental effect on the time to recognize color set members. Thus it may be possible to use as many as half a dozen colors, even for tasks involving absolute identification, without any significant decrement in performance.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100.001-1022 - "Enhanced performance with visual sonar displays." It was submitted for review on 26 Dec 1984, approved for publication on 25 Jan 1985, and designated as NSMRL Report No 1042.

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ABSTRACT

In two separate studies a modification of Sternberg's (13) memory task was used to study the effect of the set size of colored CRT presented stimuli on time to recognition. In both, set sizes from one to seven differently colored circles (memory set) were presented for a variable period of time. Subsequently, one colored circle, that had a .50 probability of belonging to the memory set, was presented and the subject responded as to whether or not he believed it belonged to the memory set. In the first study, completely different colors were used for each set size. Some significant rises in reaction time were found as set size increased but these were definitely not linear. In a second study, successive color sets were incremented by the addition of one color. This made the sets more similar to one another and also created a condition of over-learning for the sets. The results showed no significant differences among the set sizes from two to seven colors. Hence, it appears that for color sets that are fairly well learned, there is no significant effect of set size on time to recognition, at least for set sizes up to seven elements.

INTRODUCTION

There is an effort underway to switch from the use of monochromatic cathode ray tube (CRT) sonar displays to the use of chromatic displays. The current CRT displays use only green phosphors, and by adding other colored phosphors it is anticipated that some aspects of performance by sonar operators can be enhanced. Several review articles (1-3) have pointed out the supposed advantages of using chromatic CRT displays over monochromatic displays. Neri and Zanelli (4) have summarized many of the advantages and disadvantages in using color in CRTs as a coding feature. The advantages include enhancement of performance on search and identification tasks, increases in the amount of information transmitted per unit of time, and as an aid in classifying data. The disadvantages include information overload from the use of too many colors, color becoming a strong distractor when it is an irrelevant or partially redundant feature, and color being difficult to discriminate in very small targets.

The use of colors in CRT displays gives rise to many questions. One question that has been studied quite extensively is the ability of subjects to identify colors. It has been reported that as many as one million colors can be discriminated under ideal, laboratory conditions (5). However, this is quite different from the abilty to identify a set of colors on an absolute basis under a variety of conditions such as those that would normally occur in the real world. Several studies have sought to determine the number of absolutely identifiable colors, and each has arrived at a somewhat different conclusion (4-8). Feallock, et al.(8) reported the highest number of identifiable colors, with an estimate of about 24. This set, however, was achieved after extensive practice on the part of the subjects. In general, it appears that from 9 to 14 colors are easily and correctly identifiable.

Related to the question of color identification is the issue of how well colors can be remembered and how quickly they can be recalled. Several studies have superficially investigated memory of colors but only within a limited context (9-12). One question that may be of interest to designers of visual sonar CRT displays is how memory for color is affected by the number of colors a sonar operator must remember. In other words, as the set of colors used on a CRT display increases, how is recall or recognition of those colors affected? Sternberg (13) investigated how the length of a list of memorized single digit numbers affects recognition. This was done by measuring the time required to recall whether or not a test object belonged to the memory set. Sternberg presented subjects with a list of single-digit numbers that varied from one to six elements in length. Subsequently, one number was presented to the subject, whose task it was to determine if that test digit belonged to the set in memory or not. Sternberg found that as the length of the list increased, reaction time also increased linearly. In addition, Sternberg (14) studied other types of sets such as nonsense forms and photographs of faces and again found a linear

relationship between set length and reaction time. Cavanagh (15) reports on numerous studies in which the linear relationship between reaction time and set size holds over a variety of situations and different types of stimuli. However, little work has been done using color sets of different lengths and those studies done used only very limited sets of colors (11,12).

As already mentioned, identification of colors has been studied extensively; however, little or none of this work has entailed the use of CRTs, and in fact most of this work has used colored paper for stimuli. One reason for investigating CRTs separately is that the color set population generated on CRTs, compared to that of papers, is markedly limited owing to the physical characteristics of the phosphors in use. In addition, there is a qualitative difference between colors presented as self-luminous targets on a CRT and those presented as differences in reflectance on paper. In the latter case luminance differences are normally restricted to less than 30:1 whereas in the former much higher luminance differences are possible. In addition, CRT colors can be made significantly more saturated than colors produced by paper or paint. Finally, although identification of color involves a memory component, no one has attempted to study how set length of colors affects recognition or time to recall. For these reasons, we investigated how the set length of colors affects reaction time for recalling whether or not a given color stimulus belongs to the set of colors in memory. In other words, does the relationship found by Sternberg also hold for colors generated on a CRT? It is also of practical importance to know if the absolute time to recognize colors is less than or greater than that for other possible sets such as numbers or forms. If colors do enhance various types of performance, then it is important to ascertain to what extent, if any, set size will affect this enhancement.

EXPERIMENT 1

Method

Subjects. Seven color normal Submarine School students, verified with the A. O. Pseudo-Isochromatic plates, served as voluntary subjects. Those who normally wore corrective lenses did so during the experiment.

Apparatus. The subject was seated 50 cm in front of an Advanced Electronics Design (AED) color graphics CRT terminal (model # 512), which was under the control of a Digital PDP 11/04 mini-computer. To the right of the CRT terminal was a response keypad in the shape of a push-button telephone keypad. The subjects rested their arms on an armrest and placed two fingers on the keypad, one on the "1" and one on the "2".

The stimuli consisted of ten differently colored circles, 2.5 cm. in diameter (3 degrees of visual angle), which were generated on the CRT screen and presented on a dark background that had a luminance of 0.02

fL as measured with a Spectra Pritchard Model 1980A photometer. The colors were chosen so as to be easily discriminable by color normals and were designated as shown in Table I with their respective CIE coordinates. No attempt was made to equate the brightness of the colors; rather the differences in brightness were used to enhance discriminability. For example, the light blue was purposely made brighter than the dark blue.

TABLE I. Chromaticity coordinates (CIE 1931)* of colored stimuli used in Experiment 1.

Stimuli	Y	x	y
Dark Blue	3.6	.14	.05
Yellow	45.0	.42	.46
Red	16.2	.53	.33
Aqua	19.4	.23	.34
Purple	2.1	.27	.14
White	73.7	.28	.32
Orange	22.2	.50	.40
Green	54.4	.29	.53
Buff	32.3	.36	.29
Light Blue	19.4	.22	.20

* See Appendix

<u>Procedure</u>. Sets of colors ranging in size from one to seven were picked randomly by the computer from a total set of ten colors, although the subjects were not told which colors comprised the total set of ten. For a given set of trials, the number and colors in the set remained constant and comprised the positive set. Colors outside of this set were designated as the negative set. The task of the subject was to memorize the positive set and then on a subsequent test presentation, determine if the test object belonged to the color set in memory, i.e., the positive set. Each trial consisted of: (1) presentation of the positive set in the middle of the screen. The set of two consisted of two circles presented side-by-side, the set of three a triangular pattern. The set of four consisted of a diamond shaped pattern while sets five and six consisted of circular patterns. The set of seven was a circular pattern with one stimulus in the middle. The presentation time was determined by the size of the set. The positive set size of one was presented for 3 seconds, and 1 second of presentation time was added for each additional color in the set. This resulted in the set size of seven being presented for 9 seconds. (2) The CRT screen then went blank for 2 seconds. (3) An auditory warning signal was then presented. (4) The test object was presented one second after this warning signal. The test stimulus consisted of one circle presented in the middle of the screen which could be any one of the

population of ten colors. (5) The subject responded via a keypad placed to the right of the CRT screen by typing a "1" to indicate that he believed that the test object belonged to the positive set and a "2" if he believed that it did not belong to the positive set. The response and the time between the test object's appearance and the subject's response (time to recognition) were recorded by the computer. (6) Feedback about the correctness of the response was then given to the subject in the form of a printed message on the CRT screen that lasted for 5 seconds. Immediately following this a new trial was begun with the presentation of the same positive set. This procedure was similar to the fixed set paradigm used by Sternberg (13).

For any given test presentation, the probability of presenting either a positive or a negative set color was .50. All members of the positive set had an equal probability of occurrence during a positive set presentation. All members of the negative set also had an equal probability of occurrence during a negative set presentation.

Each set of trials for a given positive set size was divided into two phases. Phase 1 was considered a practice phase and continued until learning of the positive color set had reached an asymptote. The criterion for this was ten correct trials in a row with less than a 150 ms deviation in time to recognition from a continually updated mean. This stringent criterion was used to ensure that the subjects learned all of the seven set sizes equally well. Once the learning criterion was met, the subject entered phase 2, the test phase. This lasted for 20 trials. There were no procedural differences between the two phases and, in fact, the subjects never knew when they entered the test phase, but only knew when it ended. During the 20 trial test phase, as in the practice phase, negative and positive set presentations each had a .50 probability of occurrence, and hence an average 10 positive and 10 negative colors were presented during each test phase. In addition, both correct and incorrect responses were entered into the total of the 20 test trials. Only those times recorded during the test phase were used in the data analysis. This was done to ensure that all analyzed times to recognition occurred after learning of the positive set was complete.

Once a particular positive color set run was completed, the subject was allowed to rest as long as he wanted. Another positive color set run was then initiated and the procedure began again. Each subject went through all seven positive color set sizes. The average amount of time for each subject was 2 hours.

Results

Mean times to recognition for each subject were calculated for each of the seven sets for only the positive colors. Only correct responses to the positive colors were used since these were the actual colors the subjects had in memory. The negative colors had to be used during the test phase but were really not important in looking at the question of time to recognition versus set size. These data can be seen

graphically in Figure 1. A test of linearity (16) showed a significant departure from a linear relationship for these data ($F(5,42)=7.51$, $p < .01$). A significant main effect of set size was found using a one-way repeated measures ANOVA ($F(6,36)=11.2$, $p<.01$). Newman-Keuls means tests were performed to ascertain where the significant differences among the seven set sizes were. Table II shows a summary of these results. The positive set size of one yielded a significantly faster time to recognition than all of the other sets. The set of two resulted in significantly faster time to recognition than the sets of five, six and seven.

TABLE II. Results of Newman-Keuls test in Experiment 1 for differences in mean reaction time (msec) to recognize a positive color between the seven positive set sizes. Set sizes are ordered from fastest to slowest reading left to right or top to bottom.

	1	2	4	3	5	6	7
1		98**	131**	144**	206**	221**	226**
2			33	46	108*	123**	128**
4				13	75	90	95
3					62	77	82
5						15	20
6							5
7							

* $p<.05$
** $p<.01$

The number of errors made for each color during the test phase were totalled over all subjects to determine which colors were most likely confused. The total error rate (number errors/total test trials) was 5.8%. Table III shows the actual number of errors for each color made by all subjects for the seven set sizes. A chi-square test found no significant difference ($\chi^2(9)=8.44$, $p>.05$) among the colors. However, a significant difference in number of errors by set size was found ($\chi^2(6)=21.96$, $p<.01$). From Table III it can be seen that as set size increases the number of errors also increases. The exception is the set of six which has the second lowest number of errors.

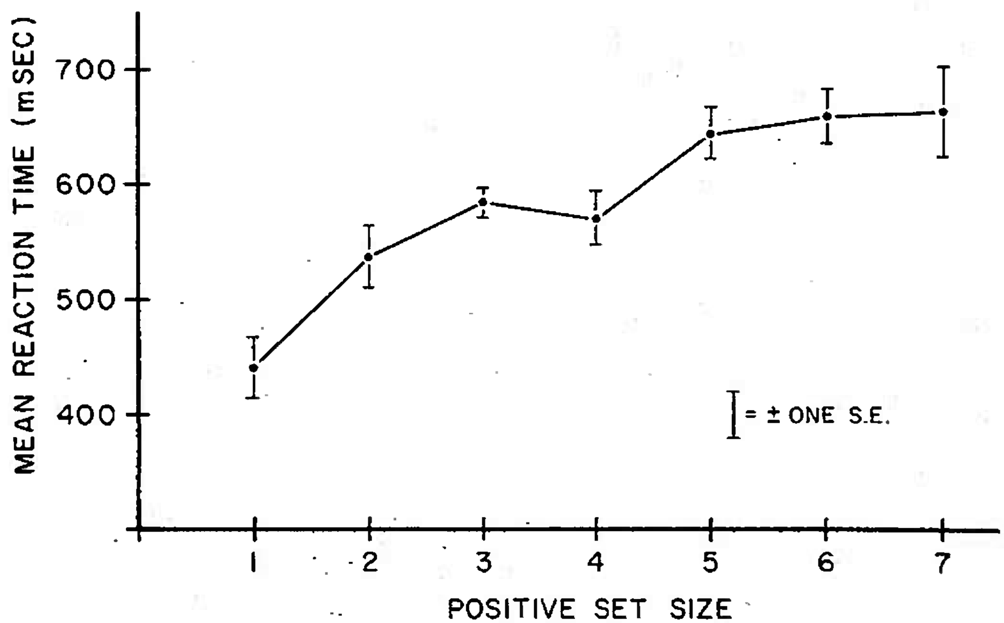

Fig. 1. Mean reaction times by set size for Experiment 1.

TABLE III. Number of errors made during the test phase in Experiment 1 totalled across all subjects.

Color	Set Size 1	2	3	4	5	6	7	Total
Dark Blue			1				1	2
Yellow						1	4	5
Red			1		1	2	1	5
Aqua		1	1	3	2	1	2	10
Purple		2			1	1	2	6
White				1	1		2	4
Orange		1			4			5
Green			4	4	1			9
Buff		1		1	2		2	6
Light Blue		1			2		2	5
Total	0	6	7	9	14	5	16	57

Discussion

As the size of the color sets increased, there was an increase in the time to recognize individual colors, but not in a linear manner. These data contrast with the functions obtained by Sternberg (13). In his studies, Sternberg found a very linear relationship between set size and time to recognition for groups of numbers as well as nonsense forms and faces. This relationship does not occur for groups of colors. One important difference between colors and numbers, however, is that colors are not all equally different from one another. The psychological difference between blue and aqua, for example, is much less than the difference between red and green. This is not true of numbers.

In the present study each positive color set was made up of not only different set sizes (one, two, three, etc.) but also different colors. For example, the set of two consisted of the colors purple and orange, while the set of three consisted of dark blue, aqua, and orange. This may explain the lack of a linear function, as the colors in some sets may have been easier to discriminate than the colors in other sets. For instance, if a different set of colors had been used for the set of four, the reaction time might have been quite different and possibly yielded a more linear relationship.

In the present work, for set sizes of six and seven, the negative set, those colors outside of the positive set, was smaller than the positive color set. Consequently, the expected rise in time to recognition for these sets may have been masked by the possibility that subjects were attending more to the negative set, which was smaller, than to the positive set. Although this question of negative set size has been studied by Sternberg (17) and found not to be a factor, Haygood and Johnson (18) found that for negative sets that are much smaller than

positive sets, subjects will sometimes switch their focus to the negative set. This switch is more efficient for the subject and will result in time to recognition being faster than if they had attended to the larger set of positive elements. Although the subjects never actually knew how large the negative set was, they usually went through well over 100 practice trials for the set of seven and may have deduced its actual size. There was actually nothing in the present paradigm that precluded them from making use of this strategy.

An additional problem with this study relates to the fact that sonar operators will learn the set of colors used in their displays very well. Clifton (19) has pointed out that sets that are overlearned do not have to be scanned as do lists that are not learned as well. For overlearned lists, no systematic rise in reaction time was found by Clifton as set size increased. Unfortunately, he never studied lists larger than four elements in length and it is questionable if this statement would hold true for lists of longer lengths. For these reasons, a second study was conducted.

EXPERIMENT 2

In an attempt to clarify the issues discussed under the first study, several modifications in the procedure were undertaken. First, the total population of colors was increased from 10 to 14. This was done to ensure that the number of elements in the negative set was never less than the number of elements in the positive set.

Second, it was decided not to produce the color sets in a random manner since it was felt that a particular color set might be more or less difficult to recognize than another set of equal size but different make-up. Rather, color sets were chosen to build on one another, so for example, the color set of one might consist of blue, set two of blue and yellow, set three of blue, yellow and red, and so on up to a color set of seven elements. In addition, to make the task somewhat easier for the subjects, it was decided to always begin with the color set of one and then present subsequent sets in order from two to seven. This also enhanced the subjects' learning of the positive set in the hopes of getting at the question of how time to recognition is affected by set size for lists that are well learned.

Method

Subjects. Eight color normal Submarine School students, verified with the A. O. Pseudo-Isochromatic Plates, served as voluntary subjects. Those who normally wore corrective lenses did so during the experiment.

Apparatus. The same apparatus used in the first study was employed again. The only exception was a change in the color population which now consisted of the colors shown in Table IV with their respective CIE coordinates. The first seven colors were those used in the positive set and were used in the order given so that the color set

of one consisted of white, set two consisted of white and light blue, set three of white, light blue, and yellow, etc. In addition, these colors were presented on a much brighter achromatic background (8.23 fL) which served to accentuate the differences between the colors. This background was always present in this second experiment.

TABLE IV. Chromaticity coordinates (CIE 1931)* of colored stimuli used in Experiment 2.

Stimuli	Y	x	y
White	75.50	.27	.30
Light Blue	16.54	.19	.18
Yellow	45.30	.42	.46
Red	3.77	.50	.29
Pale green	39.90	.27	.51
Violet	1.60	.28	.15
Orange	19.80	.55	.38
Black	0.02	.39	.43
Dark Green	1.89	.30	.59
Magenta	19.50	.22	.10
Dark Blue	1.13	.15	.05
Olive	4.62	.39	.51
Brown	2.12	.43	.39
Buff	32.30	.36	.30
Middle Gray (background)	8.23	.28	.29

* See Appendix

Procedure. The same basic procedure used in the first study was again employed, with the following exceptions. All subjects were first presented with the color set of one, followed in order by the sets two through seven. In addition, the positive set presentation time was reduced to two seconds for every trial regardless of set size. This was done because subjects in the first study felt that the positive set had been displayed for much too long a period of time.

Results

Times to recognition occurring during the test phase were again averaged for each subject by set size. As in the first study, this time increased as set size increased, and again the relationship was not linear, as determined by a test of linearity (16) ($F(5,49)=5.91$, $p <$ .01). It was, however, determined that the relationship between time to recognition and set size for sets two to seven, was not significantly different from a linear one ($F(4,42)=2.63$, $p>.05$). This relationship was also not significantly different from a line with a slope of 0 ($F(1,42)=0.97$, $p>.05$) These data can be seen graphically in Figure 2.

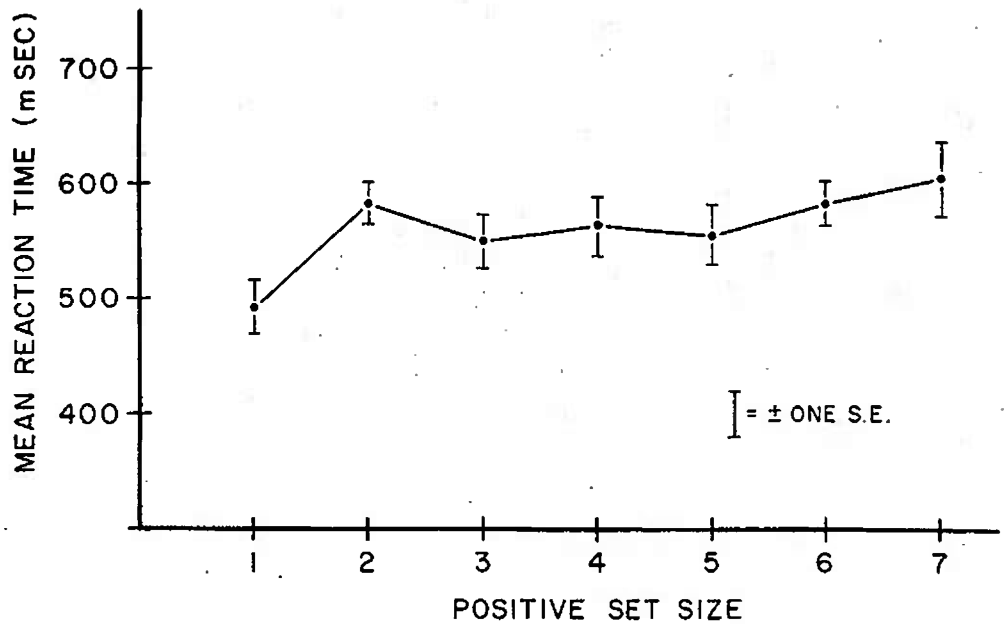

Fig. 2. Mean reaction times by set size for Experiment 2.

A one-way repeated measures ANOVA on this data revealed a significant effect of set size ($F(6,42)=2.88$, $p<.05$). Newman-Keuls means tests revealed that the set size of one yielded a significantly faster time to recognition than the set sizes of two, six and seven. No other significant differences among the means were found. Table V gives a summary of these tests.

TABLE V. Results of Newman-Keuls test in Experiment 2 for differences in mean reaction time (msec) to recognize a positive color between the seven positive set sizes. Set sizes are ordered from fastest to slowest reading left to right or top to bottom.

	1	3	5	4	6	2	7
1		57	62	70	90*	90*	112**
3			5	13	33	33	55
5				8	28	28	50
4					20	20	42
6						0	22
2							22
7							

* $p<.05$
** $p<.01$

The number of incorrect responses was again totalled over all test trials. A summary of these results can be seen in Table VI. The overall error rate was 2.5%, substantially down from the first experiment. A chi-square test found no significant difference among the number of error rates for either individual colors ($\chi^2(13)=11.0$, $p>.05$) or set size ($\chi^2(6)=9.5$, $p>.05$).

TABLE VI. Number of errors made during the test phase in Experiment 2 totalled across all subjects

	Set Size							
Color	1	2	3	4	5	6	7	Total
White		1						1
Light Blue			1		1			2
Yellow			2	1				3
Red				1	2	1		4
Pale Green								0
Violet						3	2	5
Orange					1	1		2
Black	1							1
Dark Green						1		1
Magenta					1		1	2
Dark Blue	1	1			3	1	1	7
Olive								0
Brown								0
Buff								0
Total	2	2	3	2	8	7	4	28

GENERAL DISCUSSION

The results of both studies indicate that as the number of elements in a color set increases, the time to recall a particular color also increases to some extent. This relationship between set size and time to recognition is not linear however. Clifton (19), working with sets that had been overlearned, found no significant increase in time to recognition for set sizes from two to four elements. He did find a significant rise from the set size of one to two. From the present data it appears that increasing the set size further, to six or seven for example, does not significantly increase time to recognition, if the list is well learned as in the case in this second study. It also is apparent that for well learned lists, error rate does not increase significantly with increases in set size. Hence, it appears that for set sizes up to seven colors that are well learned, time to recognition should not play a significant role in determining the number of colors to be used in a visual display. Even the statistically significant differences found in the second study are probably of little practical import, since the range in reaction time was less than 150 msec.

This study, however, points to a number of other questions which need to be answered. The first is, what is the limit of the color set to be used? In other words, how many colors can be used before causing real problems in recognition? The second question concerns the confusability of colors. It is very important to know what types of colors will be easily confused with one another so that these combinations can be avoided. Lastly, a systematic investigation of the

effect of various colored backgrounds should be undertaken. In the second study, the addition of a luminous background appeared to enhance the discriminability of the colors, and this needs further investigation.

In summary, from past research it appears that the use of color in CRT displays represents a step forward in enhancing performance in many different tasks. From the present study, it can be concluded that the addition of up to seven colors will have little or no detrimental effect on time to recognize information. In fact, it appears that color will be less affected by set size than other coding systems, such as numbers or forms, where time to recognition is very sensitive to increases in set size.

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APPENDIX

The CIE coordinates were obtained using the three filters of a Spectra Pritchard photometer (Model 1980A). A calibration correction factor was obtained for each measurement by making a visual color match between the stimulus on the CRT and a Munsell color under Illuminant C. By measuring the Munsell color, an appropriate correction factor for the photometer could then be calculated for determining the X, Y, and Z values of the unknown CRT stimuli. The Y values in the tables are given in fL.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In two separate studies a modification of Sternberg's (13) memory task was used to study the effect of the set size of colored CRT presented stimuli on time to recognition. In both, set sizes from one to seven differently colored circles (memory set) were presented for a variable period of time. Subsequently one colored circle, that had a .50 probability of belonging to the memory set, was presented and the subject responded as to whether or not he believed it belonged to the memory set. In the first study, completely different colors

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were used for each set size. Some significant rises in reaction time were found as set size increased but these were definitely not linear. In a second study, successive color sets were incremented by the addition of one color. This made the sets more similar to one another and also created a condition of over-learning for the sets. The results showed no significant differences among the set sizes from two to seven colors. Hence, it appears that for color sets that are fairly well learned, there is no significant effect of set size on time to recognition, at least for set sizes up to seven elements.